Project Name

Scintillator Based Muon System R&D

Classification (accelerator/detector:subsystem)

Detector:Muon

Institution(s) and personnel

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Project Overview:

The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. The proposed energy−flow algorithms anticipate measuring jet energies by using charged particle momenta, EM shower energies for neutral pions, and hadron calorimetry for neutrons and K_L^o. Fluctuations of the neutral hadron energies leaking from the hadron calorimeter will degrade the energy resolution. An adequately designed and proven muon system could be used to measure the energy escaping detection and improve the energy resolution of the detector.

It is in this context that we propose an R&D program for a scintillator−based muon detection and identification system.

The general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e^+e^- beamline. The scintillator strips, ~5 cm wide and 1 cm thick, would contain one or more ~1 mm diameter wavelength shifting (WLS) fibers. Light produced by a charged particle would be transported via clear fibers to multi−anode photomultipliers located outside the Fe yoke where it will be converted to electronic signals. There would be 14 planes of scintillator with alternating strips oriented at $\pm 45^o$ with respect to a projection of the beam line onto the planes.

Scintillator and Fe calorimeters have been very successfully used in neutrino experiments to measure the energy of jets. For example, with 10 cm of Fe between counters, hadronic resolutions of ~0.8/sqrt(E) are typically achieved. A scintillator strip calorimeter based on MINOS style detectors may provide the required resolution to complement upstream energy−flow measurements.

Given a substantial knowledge base from experiments like MINOS, CDHS and others one might ask if an R&D effort on a scintillator−based muon system is necessary. In fact, it is. There are significant differences in the environments for neutrino experiments and the proposed linear colliders. For the LCD, detectors must be robust and ready to withstand ~20 years of beam time in a radiation environment. The geometry and packaging of the scintillator detectors are very challenging. There is much in the way of mechanical engineering of the iron, fiber and cable routing, etc. that needs to be determined at an early stage to insure that important details for the largest LC detector system are not overlooked.

R&D Plans:

Hardware development

- Develop the mechanical and electronics specifications for a test set−up of 8 (4u & 4v) full width, but short−length strip scintillator planes.
- Procure finished strip scintillator, WLS and clear fiber sufficient for the 8 planes. Explore possible cost savings by coordination with MINOS.
- Procure approximately 16 multi−anode (64 channel ea.) photomultiplier tubes to instrument most of the 8 prototype planes.
- Borrow existing electronics for the tests we need to do, inasmuch as this is possible. This would include tube bases, discriminators, ADCs, trigger counters, trigger logic, etc.
- Use the existing cosmic ray test−stand facilities in Lab 3 that were used in the D0 fiber−tracker testing to do our cosmic ray tests.
- Obtain cosmic ray data that can be used to further define software algorithms for muon identification.
- Define the need for additional Fe in future cosmic ray and beam testing of the prototype modules.
- Develop the detailed mechanical and electronics specifications for the LC muon system.

Software development

- Muon detector simulation and tracking algorithms: detector geometry optimization, parameter tradeoffs, hit finding ability, tracking in the presence of the central field and through the magnetized Fe flux return. Understand the effects of shower leakage on the energy−flow algorithms.
- Establish physics benchmarks for the muon system from several new physics and conventional reactions that yield muons. Generate MC samples covering those physics topics to assure that the muon system is tested for these cases.
- Study the impact of background from decays of hadrons to muons in the beam lines and tracking volume. Hadron punch−through rates need to be determined and understood in the forward and central muon detectors, and accounted for in the muon system design.

Goals, Work to be done and deliverables:

Work to be Performed	By	Deliverables
Software Development	Arthur Maciel − NIU Dhiman Chakraborty − NIU David Hedin − NIU Caroline Milstene − Fermilab	muon detector simulation, muon ID and tracking algorithms
Fe Layout, Mechanical Engineering Analysis, Cable & Fiber Routing. Costs.	Kurt Krempetz − Fermilab Ray Stefanski − Fermilab Oleg Prokofiev − Fermilab	Stress/deflection calcs., Engineering drawings. R&D Cost Estimate.
Scintillator strip extrusion Processing using the NIU Machine at Fermilab.	Jerry Blazey & Alexandre Dychkant − NIU Alan Bross − Fermilab	Scintillator spec. document. 1 T prototype scint. devel. 1 T prototype scint. prod'n.
WLS R&D, Insertion in Strips; Testing; Clear fiber Splicing; Waveguide prod'n.	Alan Bross − Fermilab A. Dychkant − NIU Mitch Wayne − Notre Dame	Finished prototype scint. for prototype planes. Test results document.
Engineering &design of Prototype muon detector Planes.	Kurt Krempetz, Adam Para, Gene Fisk − Fermilab Others TBD	Engineering drawings & specification document.
Photomultiplier, electronics, logic, procurement, setup, etc..	P. Karchin − Wayne State Adam Para − Fermilab Mani Tripathi − UC Davis	Logic & test procedures for cosmic ray tests. Develop specs for LC Mu electronics
Cosmic ray test stand for Prototype module testing. (Utilize Lab 3 test stand)	Mitch Wayne − Notre Dame Caroline Milstene − Fermilab Paul Karchin − Wayne State	Mechanical layout of test stand modules. Test data analysis/results document.

Future Plans

The R&D program in the preceding table will take two years to complete. Beyond that, prototype detectors need to be built and tested. This, in turn, requires engineering to produce easily assembled, robust and reliable detectors and electronics. Cosmic ray testing (and a test stand with data acquisition) will be required to provide feedback to muon system developers on questions of signal−to−noise, etc. Further still, the development of a high energy test beam will be essential to assess progress on prototype detectors and their electronics. In addition to measurements of detector efficiency, the energy calibration and resolution obtained for a prototype assembly of Fe plates and detectors in a hadronic beam of known energy, where jets can be observed, will be of significant importance. It is likely that other tracking detectors will need to participate in such tests.

Two Year Budget − University (NSF and DOE) and Fermilab

The budget requested here assumes cost sharing between Fermilab and the collaborating universities. No LCD R&D funds are requested to support the work of Fermilab staff. The costs are to cover FY03 & FY04 although the materials costs require major commitments in FY03. NIU, through a grant from the State of Illinois, will provide $26,000/year in cost sharing of which $15,000 /year will be used for M&S. The remaining $21,000 in M&S costs over the two year period will be provided by Fermilab. The groups from Rice University and the University of Texas request no funds, but will consult on the design of the electronics and detectors, and will develop plans for their future involvement.

Item	Total	UC Davis	NIU	Notre Dame	Wayne St
Agency which funds group's base grant		DOE	NSF	NSF	DOE
M&S Costs					
Software development − use existing facilities					
Scintillator − Shared between the univs & Fermilab					
a. One ton finished scintillator strips ($10/kg)	10,000		5,000		
b. WLS fiber − for eight short modules ($3.5/m)	12,000		3,000	4,000	
c. Clear fiber	15,000			8,000	
d. Light guide manifolds	20,000			6,000	
e. Al for skins, tooling, handling fixtures,	10,000				
e. Raw materials for extrusion facility start−up					
Electronics − for 768 channels = 12 PMs					
a. Multi−anode PMs /alternate, based on M64 PM	24,000	8,000			8,000
b. Modifications to use existing electronics	10,000	4,000			4,000
M&S Cost (sub−totals)	101,000	**21,000**	**8,000**	**18,000**	**12,000**
Personnel Costs − over two years					
Software development					
a. Travel to SLAC/Fermilab		3,000	6,000		2,000
b. Engineering costs		5,000		19,500	5,000
c. Graduate and/or undergraduate students		30,000	15,000	12,000	30,000
Personnel Costs − over two years (sub−totals)	127,500	**38,000**	**21,000**	**31,500**	**37,000**
Indirect costs		8,580	11,600	12,000	7,840
Totals		**58,580**	**40,600**	**61,500**	**56,840**

Univ. Grand Total (2 years) $217,520

First Year Budget − DOE University Groups

Item	UC Davis	Wayne State
M&S Costs		
Electronics − for 768 channels = 12 PMs		
a. Multi−anode PMs /alternate, based on M64 PM	5,000	4,000
b. Modifications to use existing electronics	4,000	4,000
M&S Cost (sub−totals)	**9,000**	**8,000**
Personnel Costs		
a. Travel to SLAC/Fermilab	3,000	1,000
b. Engineering costs	2,500	2,500
c. Graduate student − 6 months salary and benefits	11,370	14,623
Personnel Costs (sub−totals)	**16,870**	**18,123**
Indirect Costs (excluding engineering for permanent equipment): 26% (UCD) 24.5% (WSU)	**3,736**	**3,828**
Totals	**29,606**	**29,951**

Experience of Collaborating Groups

The researchers proposing this work have extensive experience with muon systems and detector technology relevant to a scintillator based muon detector.

Fermilab: D0 muon detector, MINOS

NIU: D0 muon detector, calorimeter R&D, LCD simulation

Notre Dame: D0 fiber tracker

Rice: CMS muon detector

UC Davis: H1 and CMS muon detector, PMT readout and DAQ for Keck Solar2 and STACEE

UT Austin: MINOS

Wayne State: HERA−B muon detector and electronics